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Road and Rail Infrastructure V

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COMPARISON OF THE MODELS FOR ANALYSING SIGNALIZED INTERSECTIONS

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Abstract

In this paper, a comparison of three models for analysing the operation of signalized intersections (HCM 2000, SIDRA 7 and TSIS CORSIM 6.3) was performed on the basis of a detailed drivers behavioural analysis. Field data about traffic volume and distribution, headways, start-up lost time and delay were collected. Data about traffic volume and distribution, intersection geometry and signal phase times were entered in the analysed models, and the results of the models have been compared. First, the analysis was performed using default values of the model parameters and then using parameters values from the field survey. The conclusions on the models applicability, without and with the calibration of the model parameters on the local conditions, were made.

Keywords: signalized intersection, delay, saturation headway

1 Introduction

The city street network capacity is limited by the capacity of the intersections due to recurring interruptions of traffic, numerous vehicle and pedestrian conflicts as well as a limited number of lanes. Therefore, it is very important to accurately estimate the intersection performance and to determine the appropriate geometry. This paper analyses the reliability of the most used models for the analysis of isolated signalized intersections (HCM [1], SIDRA [2], CORSIM [3]). The aim of the paper is to determine the possibility of applying these models in the local conditions and to determine the complexity of calibration. HCM and SIDRA are analytical deterministic models with similar theoretic background (gap acceptance), with SIDRA having the possibility of a more detailed description of traffic (lane by lane analysis, permitted left turns, impact on queue length of auxiliary lane on through traffic capacity). CORSIM is a stochastic simulation model which means that for the same input data it gives different results in each simulation. Isolated intersections are most often analysed with deterministic models (because they have fewer parameters to calibrate such as headway and start-up lost time), while simulation models are most often used in analysis of part of city street network with corresponding intersections.

2 Field Survey

2.1 Analyzed intersection location and configuration

The observed intersection is located in Split, at the crossroads of Bruna Bušića and Poljička cesta street (Figure 1). Poljička cesta is long main city road that extends from the entrance to the city to its centre and therefore has one of the most heavily traffic volume.

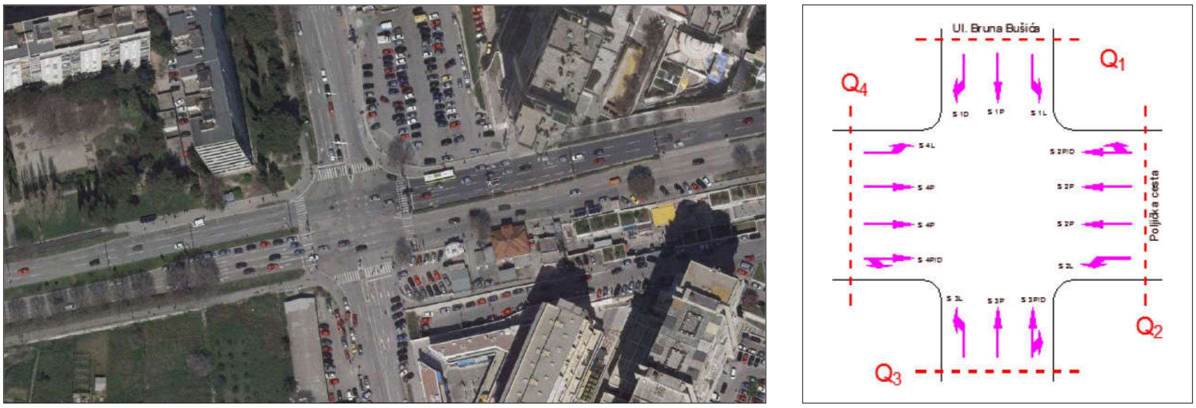

Figure 1 Observed intersection

Direction Q1 is the northern approach (Bruna Bušića) and consists of 3 traffic lanes (short left lane and 2 full lanes). Direction Q2 is east approach which consists of 4 traffic lanes (two for through movements, one shared lane for through and right turns, and one exclusive short left lane). Q3 is the southern approach and consists of 3 traffic lanes (one short left lane, one for through and one shared lane for through and right). The Q4 is the west approach and has the same geometry as the Q3. Intersection is signalized in four phases. The approaches Q1 and Q3 have the same phase in which the compound phase of the left turn appears. The approaches Q2 and Q4 have the same phase duration, but there is a completely-protected phase for left turns. The cycle duration is 90 seconds, and the duration of each phase is shown in Figure 2.

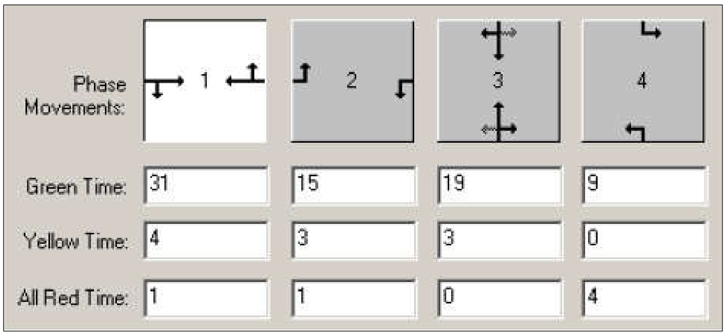

Figure 2 Phase duration

2.2 Traffic volume

Traffic data were collected with video camera in the morning peak hour from 7:15 to 8:15. Recording was performed during good weather and other conditions on Wednesday, March 14, 2017. The volume and distribution of vehicles and pedestrians for each of approaches are shown in Figure 3.

2.3 Saturation headway, start-up lost time and time-in-queue delay

Headways of vehicles that were in the queue from the beginning of the green phase to the appearance of the first non-personal vehicle were recorded at each lane. This provided the data needed to calculate the saturation headway and start-up-lost time what are input models data. In addition, for each vehicle, time-in-queue delay, i.e. the total time from a vehicle joined the queue to its discharge across the stop lane was recorded. The saturation headway is the average value of the measured headways from the fifth to the last vehicle in the queue before the start of the green phase or until the occurrence of a vehicle that is not personal (truck, bus, ...) [4].

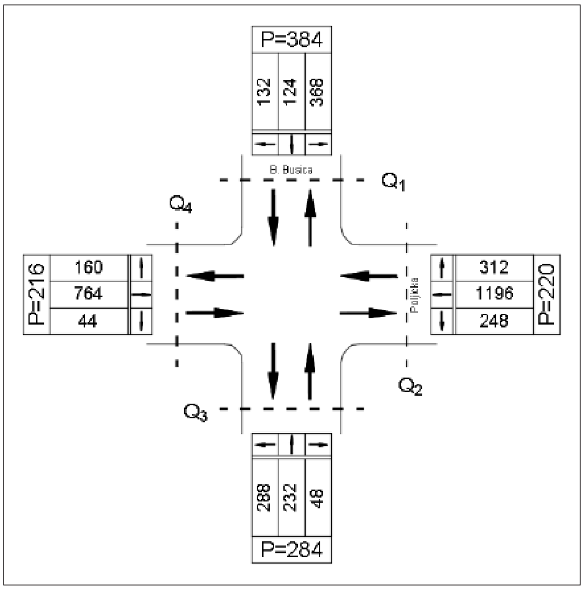

Figure 3 Volume of vehicles and pedestrians (P) in the morning peak hour

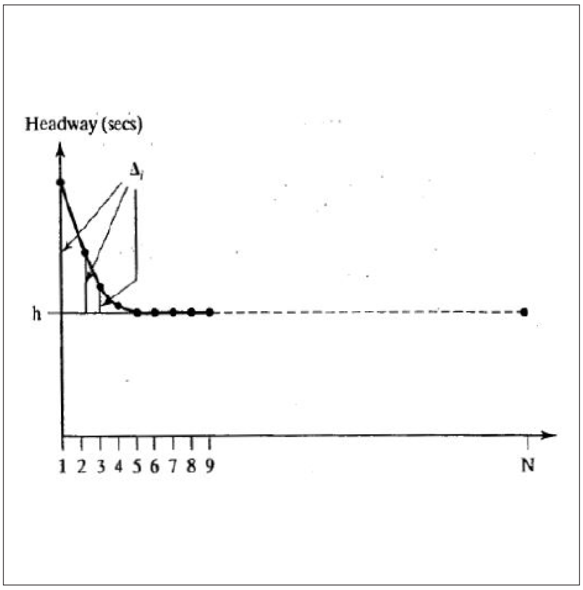

Figure 4 Flow from the queue at signalized intersection [4]

From Figure 4 one can see how first few vehicles (4) have greater headway because they have to react and accelerate. The additional time above and beyond headway h is defined as start-up lost time:

$$l_1 = \sum_i \Delta_i \tag{1}$$

Where:

l_1 – Start-up Lost Time (sek/phase);
Δ_i – incremental headway (above 'h' seconds) for vehicle i.

2.4 Delay

Delay is the most commonly used measure for describing the operation of a signalized intersection. Delay can be determined in many ways such as stopped delay, control delay, time-in-queue delay etc. Stopped delay is time vehicle is stopped in queue while waiting to pass through the intersection. Time-in-queue delay is time from the vehicle joining the intersection queue to its discharge across the intersection on departure. Control delay is the delay caused by a control device. It is approximately equal to time-in-queue delay plus the acceleration-deceleration delay component.
In this project was used most common form of delay i.e. control delay. It is hard to measure control delay in the field so here was measured time-in-queue delay. Control delay was obtained by adding the time required to decelerate from the desired speed to 0 and the acceleration time. This is more precise than the HCM methodology (where the number of vehicles in the queue at 10 or 20 s intervals are multiplied by the duration of intervals and corrected by the factor 0.9) because time-in-queue delay was measured for each vehicle. The deceleration and acceleration times were obtained using typical rates (2.5 m / sec^2) at intersections [5-7]. In order to achieve deceleration and the acceleration times, the measured percentages of vehicles arrivals on green and red light were used. For vehicles that arrived on green, and passed through the intersection without deceleration, was assumed that they have no acceleration-deceleration lost time. Thus, the average time lost for acceleration/deceleration is obtained by dividing the sum of lost times (for vehicles that came on red or came at the end of the green light but did not pass the intersection) with the total number of vehicles.

The measurements were carried out in the time period of 7:30 to 7:45 when all maneuvers on approaches Q1 and Q2 were operated at the capacity limit (occasionally the queue remains at the end of the green but at the end of the analyzed time interval queues were cleared). In this 15-minute interval, 10 cycles were recorded with a video camera and processed by Android application (Headway) developed by programming language Sketchware [8]. Using this application headway and start-up lost time were determined. Android application Delay Study (Aspen Technic) [9] was used to measure time-in-queue delay. Of the 10 measured values, the average value of each parameter was obtained. Measurements were made for each lane as well as for each turning maneuver. It is assumed that for headway estimation were relevant only through movements in middle two lanes, where the vehicles go through without interaction with other turning vehicles. Table 1 shows average measured values (sec) of saturated headway (SH), start-up lost time (SULT) and average time-in-queue delay (AST) for approach Q2:

Table 1 Average measured values on approach Q2

	Q2		
Maneuver	**SH**	**SULT**	**AST**
Left	2,3	1,0	44,0
Through	1,8	1,7	40,2
Through	1,8	1,8	35,8
Right	3,0	1,0	50,1

The smallest saturated headway of personal vehicles was recorded on middle (through) lanes of approach Q2 and this value was taken as input data in the models. Approach Q4 has a something higher saturated headway (2 sec), even though it has the same geometric elements, but the traffic volume is twice as few, so drivers are more relaxed because they wait less. Other lanes have higher headways because they are intended for turning right and left. In this way, input data for the model (saturation headway and start-up lost time) and data representing model functionality (delay) were obtained.

3 Comparision of models

Data about intersection geometry, size and distribution of vehicle and pedestrian traffic volumes, bus stop data and signal data have been entered in the analyzed models. The comparison of delays estimated by used models with the delays measured in the field was analyzed for the following cases:

- Case 1 – Comparison of results for default values of the models (saturation headway, start-up lost time, arrival type) and
- Case 2 – Comparison of results for measured values of headways, start-up-lost time and percentage of vehicles arrival on green light.

3.1 Case 1 – Comparison of results for default values of the models

Table 2 shows delays estimated by models as well as measured delays. HCM 2000 does not give results separately for right and right turns when there is at least one shared lane for these maneuvers, rather it gives results for lane group through + right (T + R) shown in last column of Table 2. Other models estimate delays for each maneuver.

With green are marked delays that result with the same LOS as field measured delays. Red color show delays that result in 1 LOS difference and bold red show delays resulting with difference of 2 LOS between estimated and measured delays. From the results it can be seen that only HCM results with difference of 2 LOS between measured and estimated values, always

for left turn. The cause is in the methodology for calculating delays of left turning vehicles. Fundamental concept of HCM is that left turning vehicles have no impact on the operation of the subject approach until the first left-turning vehicle arrives. The methodology for estimating the portions of the effective gren time before the first left turning vehicle arrives on the subject approach are based primarily on regreession equations developed using data on intersections approaches in USA. On the other hand SIDRA uses well known queuing theory (gap acceptance process) to estimate capacity and delay for permitted left turning vehicles as used in methodology for unsignalized intersections. Corsim is also based on the queuing theory.
So HCM gives unrealistic high delays for left turning vehicles, especially for permitted left turning, while SIDRA and Corsim results with much reliable prediction. For left turning vehicles the best prediction of delay is achieved by Corsim. For right and through movements, regarded as lane group, the best results gives HCM; for all approaches there is no difference in level of service of modelled delay and measured delay. For right turns SIDRA overestimates the effect of pedestrians and result with higher delay than measured, while Corsim predict these delays better. For through movements Sidra predict delays better than Corsim which underestimates delays.

Table 2 Measured and estimated delays using default models parameters

	Case 1	Delay (sec/veh)/LOS/DIFF.(%)			
		Left	Through	Right	T+R Lane Group
Q1	SIDRA	73/E/+59	33/C/+14	49/D/+63	
	HCM	120/F/+260	32/C/+10	46/D/+53	
	CORSIM	36/D/-22	41/D/+41	36/D/+20	
	MEASURED	46/D	29/C	30/C	
Q2	SIDRA	54/D/+23	64/E/+36	75/E/+50	
	HCM	82/F/+86	-	-	55/D/+17
	CORSIM	44/D/0	28/C/-41	64/E/+28	
	MEASURED	44/D	47/D	50/D	47/D
Q3	SIDRA	49/D/+63	35/D/0	43/D/+43	
	HCM	58/E/+93	-	-	33/C/-3
	CORSIM	27/C/-10	29/C/-17	33/C/+10	
	MEASURED	30/C	35/CD	30/C	34/C+C
Q4	SIDRA	43/D/+2	26/C/-26	33/C/+6	
	HCM	43/D/+2	-	-	25/C/-29
	CORSIM	33/C/-21	19/B/-46	23/C/-26	
	MEASURED	42/D	35/CD	31/C	35/CD

3.2 Case 2 – Comparison of results for measured values of headways, start-up-lost time and percentage of vehicles arrival on green light

The table 3 shows the results of estimated delays by models using parameters measured in the field. The value of the saturation headway measured in the middle two lane of approach Q2, in which there is no turning maneuvers, is 1.82 , i.e. the saturated flow is 1970 veh/hour. Measured start up lost time is 2 seconds, and the percentage of vehicles arrivals on green light used in SIDRA or arrival type used in HCM are shown in the table 4.

Table 3 Measured and estimated delays by models using measured parameters

	Case 1	Delay (sec/veh)/LOS/DIFF.(%)			
		Left	Through	Right	T+R Lane Group
Q1	SIDRA	50/D/+8	33/C/+14	41/D/+37	
	HCM	100/F/+217	32/C/+10	44/D/+47	
	CORSIM	37/D/-20	41/D/+41	32/C/+6	
	MEASURED	46/D	29/C	30/C	
Q2	SIDRA	52/D/+18	39/D-17	41/D/-18	
	HCM	74/E/+68			45/D/-4
	CORSIM	42/D/-5	27/C/-43	59/E/+18	
	MEASURED	44/D	47/D	50/D	47/D
Q3	SIDRA	40/D/+33	20/C/-43	31/C/+3	
	HCM	51/D/70			27/C/-21
	CORSIM	26/C/-13	28/C/-20	30/C/0	
	MEASURED	30/C	35/CD	30/C	34/C
Q4	SIDRA	43/D/+2	26/C/-26	33/C/+6	
	HCM	42/D/0			24/C/-31
	CORSIM	33/C/-21	19/B/-46	23/C/-26	
	MEASURED	42/D	35/CD	31/C	35/CD

The values of Platoon ratio and corresponding arrival types are shown in table 5.

Table 4 Arrivals during green, i.e. arrival type

		left	through	right
Q1	arrival during green (%)	53	27	31
	arrival type	6	2	
Q2	arrival during green (%)	22	61	52
	arrival type	4	5	
Q3	arrival during green (%)	36	58	25
	arrival type	4	4	
Q4	arrival during green (%)	23	39	33
	arrival type	2	5	4

Table 5 Platoon ratio

Arrival type	Platoon Ratio, $P_A = Pg / u$; $u = g / c$	
	Range	Default
1	PA ≤ 0.50	0.333
2	0.50 ‹ PA ≤ 0.95	0.667
3	0.95 ‹ PA ≤ 1.05	1.000
4	1.05 ‹ PA ≤ 1.50	1.333
5	1.50 ‹ PA ≤ 1.85	1.667

Arrival type is calculated using Platoon Ratio i.e. PA = Pg / u; u = g / c; where Pg = proportion of arrivals on green; g = green phase; c = cycle length. All models have resulted in better estimates of delays and LOS.

CORSIM has the slightest improvement because it is not intended for the analysis of isolated intersections, so it cannot model the mode of arrival at intersections in terms of arrivals on green light. Only the distribution of vehicle arrivals on the road network (erlang, uniform and normal) can be changed. For a more accurate estimation of delays at the intersection, upstream and downstream intersections should be modeled with volumes size and distribution, signal phases and offsets.

HCM again resulted in the wrong estimation for two levels of service for left turns. SIDRA has resulted in 9 accurate LOS estimates and has misjudged LOS for 1 level for 3 maneuvers (once for right (Q1), once for left (Q3) and once for right turn (Q3). CORSIM has resulted in accurate LOS estimates for 7 maneuver movements and has misjudged LOS for 1 level for 5 maneuver movements.

4 Conclusion

SIDRA and CORSIM resulted in pretty good estimates using the default model parameters because LOS for various movements was wrongly estimated just for 1 level. SIDRA and CORSIM have accurately estimated LOS for 6 maneuver movements, and for 6 they made a mistake for 1 level. On the other hand, HCM has correctly estimated the LOS for 5 maneuver movements, while has misjudged LOS for 4 maneuvers, of which 3 for 2 levels, all of them for left turns (Q1, Q2, Q3).
It can be concluded that HCM is not reliable in estimating LOS for left turns due to the methodology. The basic concept of HCM is that left turning vehicles have no impact on the operation of the subject approach until the first left-turning vehicle arrives. The methodology for estimating the portions of the effective green times is based primarily on regression equations developed on USA intersections which is obviously not applicable in other conditions (regions).
By calibrating model parameters, much better estimates were obtained. After calibration, SIDRA resulted in 9 accurate estimates of LOS (before the calibration was 6) and has misjudged LOS for 1 level for 3 movements, once for right (Q1), once for left (Q3) and once for right movement (Q3).
CORSIM has resulted in accurate LOS estimates for 7 maneuver movements and has misjudged LOS for 1 level for 5 maneuver movements.
After calibration, HCM resulted in 4 false estimates, which is as before calibration, but with smaller errors in the delay estimation. Also, for one maneuver, the error of estimation decreased from 2 to 1 LOS.
Considering that the ratio of traffic volumes and capacities on the intersection approaches have range from about 0.5 to 1, it can be concluded that SIDRA and CORSIM can be reliably used for a wide range of volumes, while HCM is not reliable in LOS estimates for left turn maneuvers. In case of having local data on model parameters, the best results are given by SIDRA which can be recommended for evaluation of LOS in various conditions.

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